Simulation Based POD Estimation for Radiographic Testing of Turbine Blades

Hans-Uwe BARON*, Benjamin HENKEL*, Carsten BELLON**, Andreas DERESCH**,
* MTU Aero Engines AG,
** BAM Bundesanstalt für Materialforschung und -prüfung,

Abstract

During manufacturing of turbine blades in some cases pores can appear. A pore is a possible starting point of a crack, which can cause breakage of the blade.

Here radiographic inspection is employed for finding such pores within the turbine blade roots.

As a measure for the reliability of the inspection the probability of detection (POD) is evaluated. There are several disadvantages, like costs and time for preparing and evaluating a lot of parts with defined defects, when carrying out a real POD trial. In addition, not every kind of defect can be manufactured anywhere in the blade. Radiographic simulation software presents an opportunity to estimate the POD without these disadvantages. In this case the simulation software aRTist is applied to a real example from the aero engine manufacturing industry.

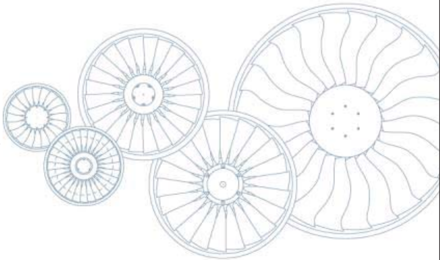
In the first step a real X-ray image with film or digital detector is made and this inspection is set up in the simulation software with the same boundary conditions (e.g. geometrical conditions, X-ray spectrum, material composition, detector). Then the image quality of the simulation is adapted to the real X-ray exposure. The adaptation is done based on measurements of contrast to noise ratio (CNR) and signal to noise ratio (SNR) on the 2-2T hole of a step wedge with an IQI according to ASTM 1742. In the simulation a defect is created in the region of interest. This defect can be varied using the SimuPOD module of the aRTist software. All the simulated images with the defect variations are automatically evaluated relating to flaw detectability. After setting a threshold in the â-vs.-a curve the POD curve and the $a_{90/95}$ value are calculated.

With this simulation based method a very fast and cheap POD calculation is possible for many kinds of defect and also in every region of the inspected part. Only a few calibration and validation images with simple test parts are necessary.

MTU Aero Engines

BAM Bundesanstalt für Materialforschung und -prüfung

Simulation based POD estimation for radiographic testing of turbine blades



H.-U. Baron, B. Henkel, MTU Aero Engines, München, Germany

C. Bellon, A. Deresch, BAM, Berlin, Germany

MTU Aero Engines

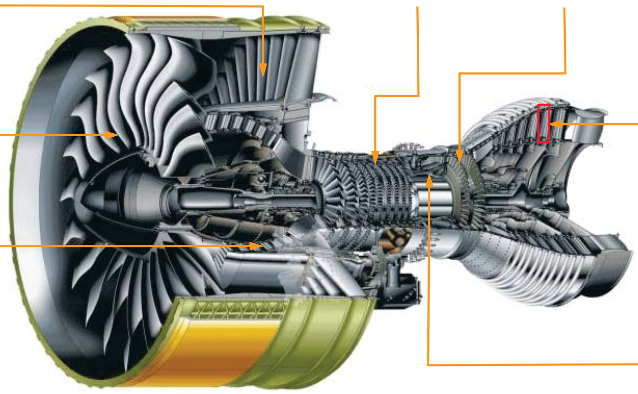
Outline

- **Product**
- **Motivation**
- **Procedure**
  - Real X-ray Image
  - Simulated X-ray Image
  - Validation
  - RT simulation supported POD method
- **Resulting POD**
- **Summary and Conclusions**

Product: Airbus A380

- Biggest airliner in the world
- max. speed: 945 km/h
- max. passengers: 853
- max take off weight: 560 t
- Range: 15000 km
- 4 Turbofan engines (GP7000)

Product: GP7000



- Fan diameter 2.96 m
- Take-off thrust 311 kN
- Bypass ratio 9:1
- Rotational frequency 18000 1/min
- Partners: P&W, GE, Snecma, Techspace Aero
- MTU share 22.5 %

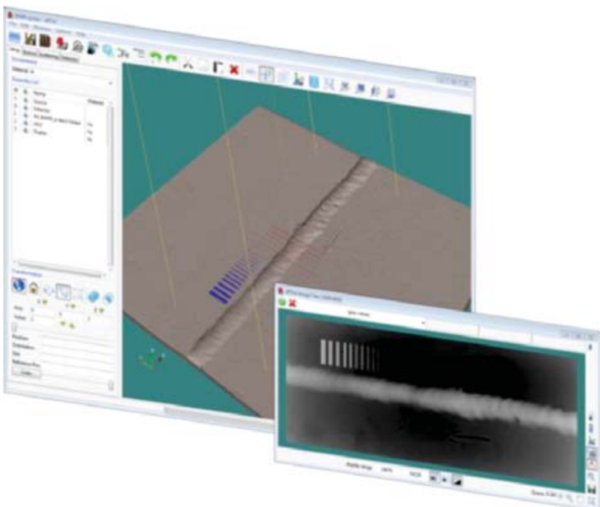
Motivation: POD of Blade Root Inspection

- Different defect limits for different zones (e.g. 0.6 mm defect size in blade root)
- For a reliable statement about detectability of the different defects a POD calculation has to be done
- Disadvantages when using real POD calculation
  - Large number of parts have to be prepared
  - Time consuming
  - Costs
  - Not every defect can be manufactured in different sizes and at different positions

➔ Solution = Simulation based POD

Motivation: RT Simulator

aRTist is an easy to use and practical simulation tool generating realistic radiographic images from virtual scenes

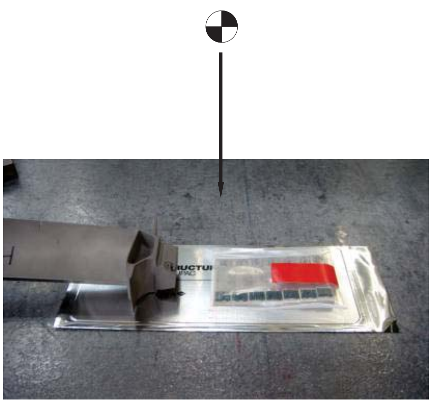


- analytical + Monte-Carlo model
- multi core support & GPU usage
- live preview; undo/redo functionality; mouse interaction

Procedure: RT simulation supported POD method

- Exposure of real X-ray image with IQI on step wedge
- Simulation of X-ray image
  - Same geometrical conditions
  - Same X-ray spectrum
  - Same detector
- Adapt image quality of simulation to real X-ray image
  - Visibility of 2-2T hole
  - Values for SNR and Contrast
- Creation of defect in simulated X-ray image
- Validation by comparison of simulated X-ray image with real X-ray image with defect
- Define variation of defect and X-ray parameters
  - Defect size, position, kV, mA
- Simulation and calculation of â-vs-a data
- Definition of decision threshold in â-vs-a curve
- POD curve and $a_{90/95}$ value

Procedure: Real X-ray Image



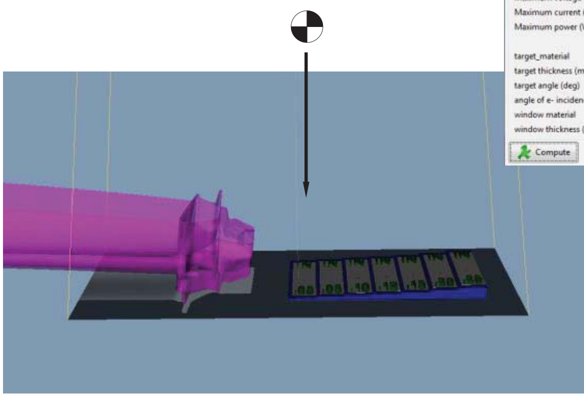
X-ray Tube
Type: Isovolt150
Focal Spot Size: 5.5 x 5.5 mm²
Voltage: 120 kV
Current: 15 mA
Time: 60s

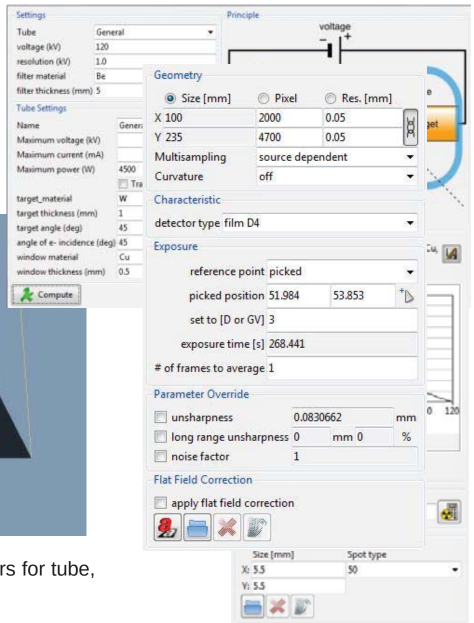
Film
Type: Agfa D4
Size: 10 x 24 cm
Packing: Vacupac
Screens: 0.02 / 0.02 mm Pb

Geometry
Film Focus Distance: 1000 mm
Film Part Distance: Close Contact

MTU Aero Engines

Procedure: Simulation of X-ray Image





Simulation of the X-ray image with the same parameters for tube, film, and geometry as in reality.

MTU Aero Engines

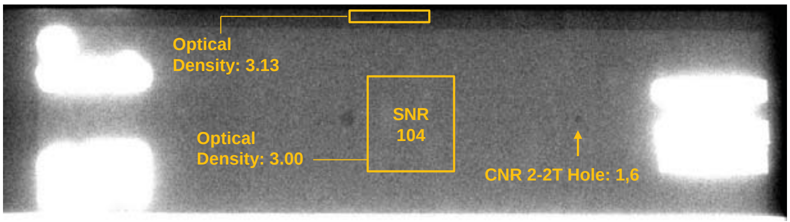
Procedure: Adapt image quality of simulation to real X-ray image

- Adapt essential image quality parameters to experiment: SNR, contrast and differential contrast

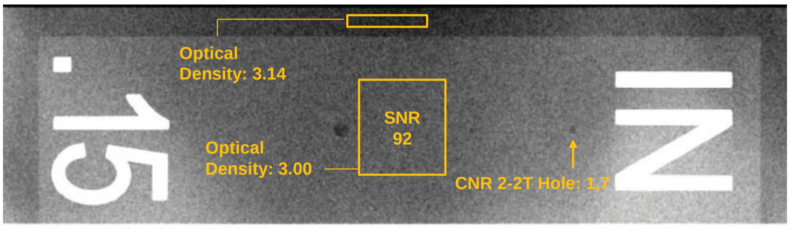
- Adjustments can be done using simple test exposures

- Simulator settings
  - Spectrum – kilovoltage
  - Material – composition, density
  - Scattering – scatter ratio
  - Detector – unsharpness, noise
  - Exposure – tube current, time
  - …

Procedure: Adapt image quality of simulation to real X-ray image



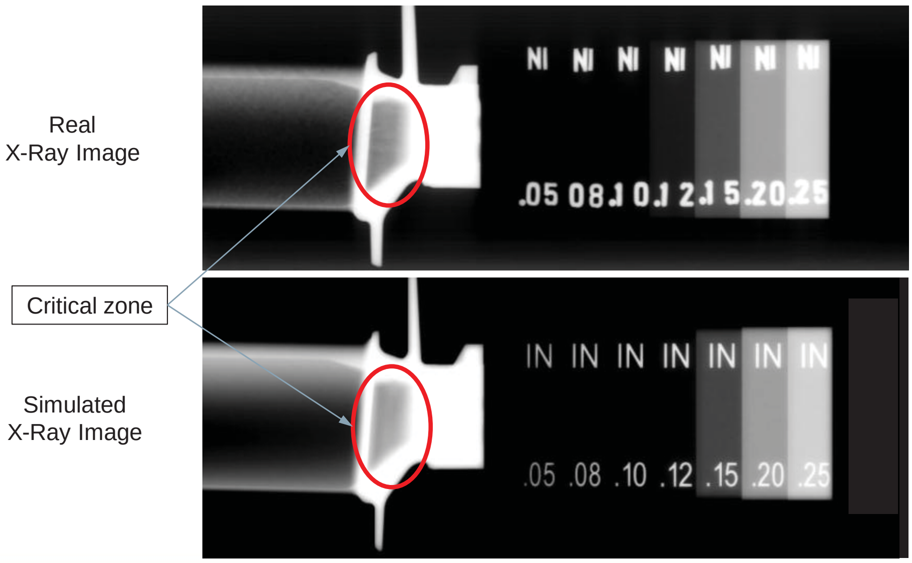
Real X-ray image



Simulated X-ray image

2-2T Hole ≙ Defect with ø 0,508 mm and depth 0,076 mm

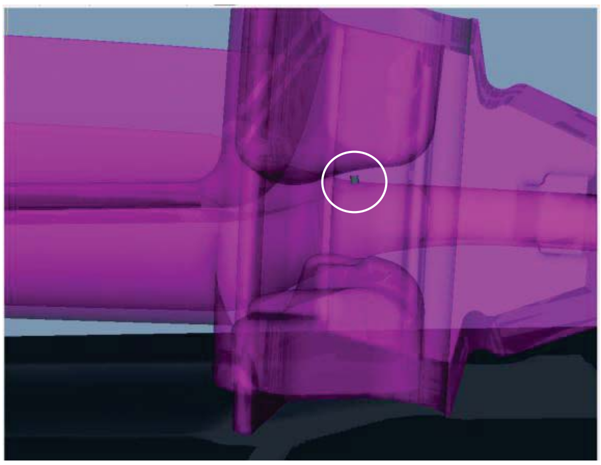
Procedure: Comparison between simulated and real X-ray image



Procedure: Creation of defect in simulated X-ray image

- Defect: Cylinder
- Diameter = Depth
- Exposure direction is parallel to cylinder axis

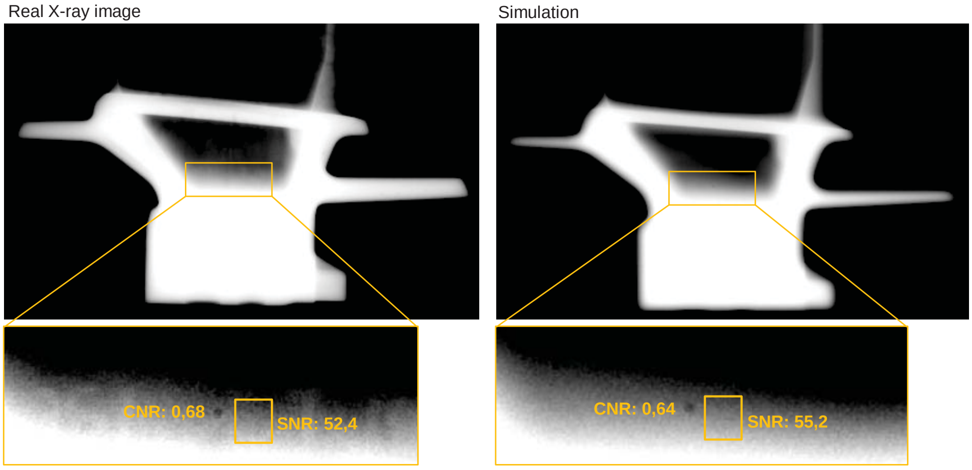
Variation of size and position



Procedure: Validation of the simulated X-ray image

Defect size 0,4 mm cylinder (depth and diameter)

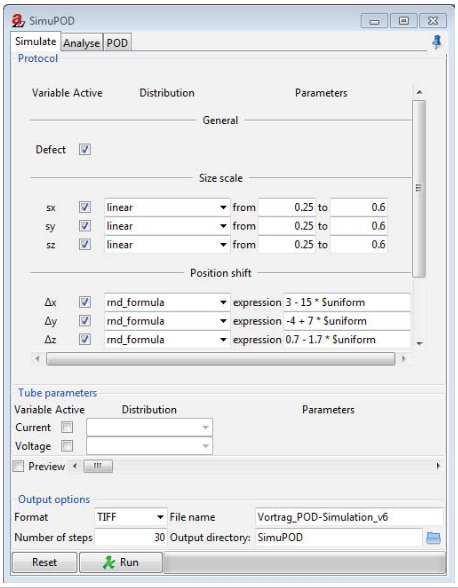
Real X-ray image | Simulation



Deviation between simulation and real X-ray image ≈ 5% ➔ acceptable

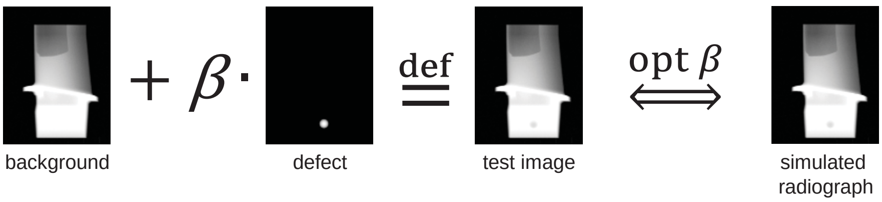
Procedure: Simulation and Calculation of POD

- aRTist module *SimuPOD*
  Generate POD from synthetic radiographs
  - Simulate defects of varying size
  - Overlay random variations
  - User-friendly input
  - Automatic image evaluation
- Repeated simulation with variation of defect and/or X-ray parameters (deterministic/stochastic distributions)
- Applied variations for this test case:
  - Defect size … from 0.25 to 0.6 mm
  - Defect position … linear, uniform
  - Tube position … ± 2 cm, uniform



Procedure
Determination of â from simulated radiographs

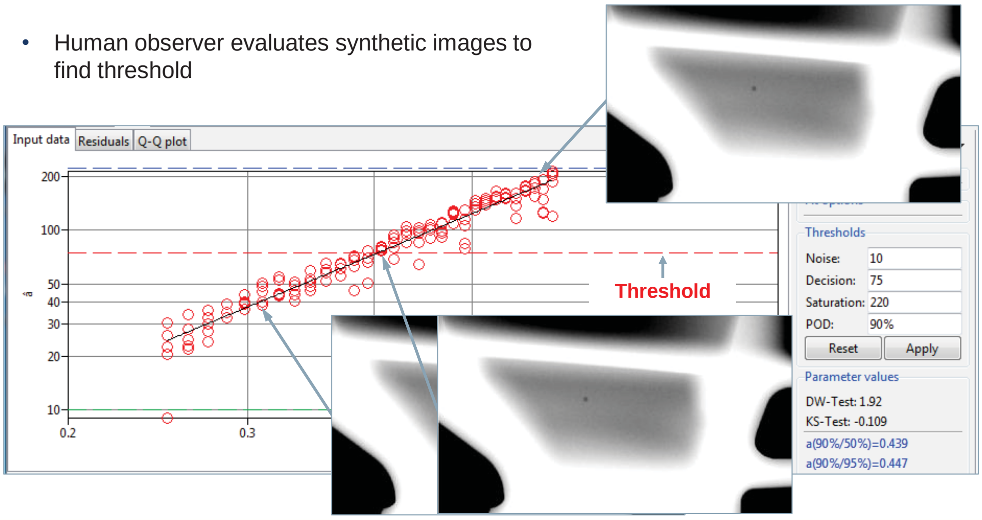
- Visibility of defects must be estimated by software
- Use a model observer (derived from the Bayesian ideal observer)
  - Models characteristics of human observer
  - background & defect known



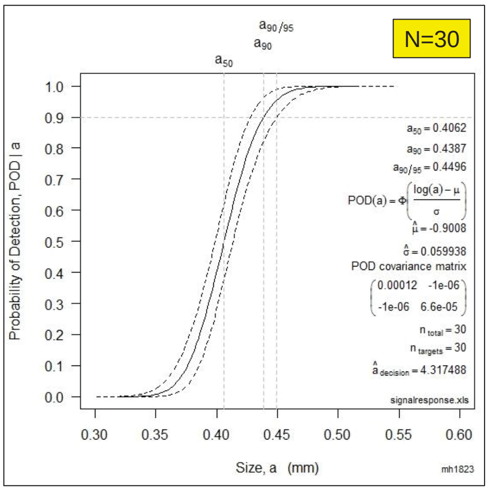
- Compute β and standard deviation σ_β via linear regression
- t-test for significance of defect: $\hat{a} = \frac{\beta}{\sigma_\beta}$

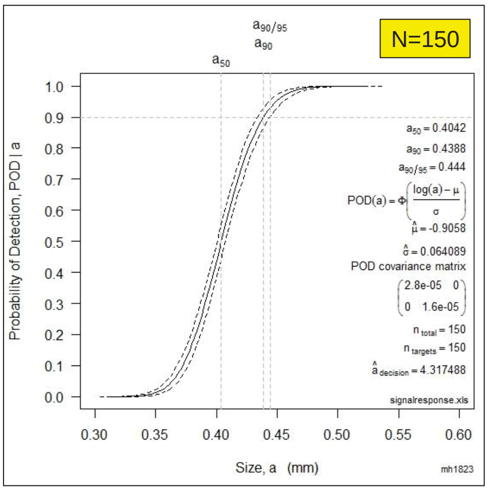
Procedure
Definition of decision threshold for POD

- Human observer evaluates synthetic images to find threshold



Procedure: Final POD





Using 150 instead of 30 data points change the a90/95 value from 0.45mm to 0.44mm

3. Summary and Conclusions

- **RT simulation supported POD method is possible**
- Simulation needs to be calibrated to reproduce the experimental image quality
- Method works well for film and digital radiography of compact defects and automated defect recognition
- Ongoing validation of the method is necessary (influence of the human inspector unknown)
- Only simple calibration and validation images are required -> **fast and cheap**